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Iron and Zinc Deficiencies in Selected Calcareous Soils of Southern Utah

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IRON AND ZINC DEFICIENCIES IN SELECTED

CALCAREOUS SOILS OF SOUTHERN UTAH

by

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E. Frank Schnitzer

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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by

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The response of field corn to iron and zinc fertilization was studied using a split plot experimental design in Millard County, Utah, in cooperation with the Utah State University Extension Agent and a local farmer. Mainplot treatment applications consisted, on an acre basis, of (1) 5 tons of sulfuric acid, (2) 1 ton sulfuric acid, (3) 1.8 tons gypsum, (4) check plot. Subplot treatments were (1) Fe at 5 lbs/Ac, (2) Zn at 10 lbs/Ac, (3) Fe and Zn at 5 and 10 lb/Ac, respectively, (4) check plot. The iron and zinc applications were essentially rendered unavailable by reactions of the applied iron and zinc with the highly calcareous soil matrix. Experimental variability and the relatively low rates of applied micronutrients combined to produce insignificant yield responses to micronutrient fertilization.

Another study was conducted to predict the soil iron critical level. Five soils from Millard County, representing some of the soils low in iron and zinc, were selected for a greenhouse study.

All five of the soils were equally divided into three groups and assigned one of three pretreatments. One-third of the soils were stressed by successive croppings with corn and oats. One-third of the soils were fertilized with Fe chelate and $ZnSO_4$ at 5 ppm each as a pretreatment. And one-third of the soils did not receive a pretreatment. The pretreatments were designed to obtain a broader range of soil iron concentrations.

After the pretreatments were completed on all of the soils, a randomized block experimental design was employed to measure potential yield increases in corn produced by the addition of Fe chelate. Two corn genotypes, an iron-efficient corn inbred (WF9) and an iron-inefficient corn mutant (Ysl/Ysl), were utilized in the greenhouse study. The treatments were (1) 5 ppm Fe chelate plus corn inbred WF9, (2) 5 ppm Fe chelate plus corn mutant Ysl/Ysl, (3) no Fe addition plus corn inbred WF9, (4) no Fe addition plus corn mutant Ysl/Ysl.

Significant yield responses to Fe fertilization were determined by an LSD statistical test. Generally, soils with a DTPA extractable iron level greater than 5 ppm did not respond to applied iron. Similar yield responses were obtained for the iron-efficient and iron-inefficient varieties. A tentative critical level of DTPA extractable iron of 5 ppm was proposed for the calcareous soils of Millard County, Utah.

(67 pages)

INTRODUCTION

On a worldwide basis, there exists a need to maintain a high level of food production. Maximum cultivated crop yields are sustained by reducing the factors which limit plant growth. Additional efforts to increase crop production have promoted the large scale conversion of arid lands into agricultural lands through the use of irrigation water. Due to the reduction in the acreage of prime agricultural land, increasing demand is being placed on lands marginally suited for agriculture. Solutions to problems limiting crop yield on marginal lands are a major concern to the agriculturist. Two management options available are soil reclamation and utilization of plant varieties adapted to calcic soils.

Approximately one-third of the earth's surface is in arid or semi-arid regions. A predominant feature of the soils in these minimum rainfall regions is the presence of alkaline earth carbonates in the profile. A major plant nutritional problem associated with calcareous soils is chlorosis. Calcareous soils often produce chlorotic plants which exhibit a distinct interveinal yellowing of the leaves. This "lime induced" chlorosis is typically a deficiency of iron and/or zinc within the plant. Both iron and zinc are essential elements for optimum plant growth. Alkaline soil environments sometimes limit the availability of these essential micronutrient elements to the plant. The predominant soluble salts found in alkaline soils include sodium, calcium, and magnesium chlorides, bicarbonates, and sulfates with the common occurrence of both alkaline earth carbonates, calcite, $CaCO_3$ and dolomite, $CaMg(CO_3)_2$, and gypsum, $CaSO_4 \cdot 2H_2O$. The solubility of iron and zinc in the soil solution which is related to its availability to plants is dependent on the activity of iron and/or zinc in the soil solution in relation to the concentration of other soluble cations.

Recently areas in Millard County in south-central Utah have been brought under cultivation because of the development of new sources for irrigation, usually pump wells. Many crops, especially corn, have shown various chlorotic symptoms that suggest they may be suffering from iron and/or zinc deficiencies. The soils that these crops are grown on are calcareous, alkaline, and in some areas tend to be saline. Chelate extraction of iron and zinc from the soils predict only low to marginal amounts of available iron and zinc.

A reliable soil test is a management tool used to predict the nutritional needs of plants. Soil tests are developed for separating soils into deficient and non-deficient categories by determining a critical level below which a crop will respond to fertilization. Evaluation of soil tests is based largely on their success or failure to distinguish between soils that are responsive and nonresponsive to fertilizer additions.

This study examines the potential of soil applications of iron chelates as a management practice in Utah. The soil iron critical level obtained from selected Utah soils will be compared with critical levels established in neighboring states. Specific objectives of this study are listed below:

1. To correlate the soil iron level obtained by chelate extraction with yield increase in corn for the purpose of establishing a critical level for soil iron.

2. To obtain information on the feasibility of iron, zinc, and sulfuric acid applications to field soils.

LITERATURE REVIEW

Micronutrient deficiencies in field crops are difficult to predict since micro elements are needed in very small amounts relative to other nutrients. An important consideration when studying micronutrient nutrition is the ability of the soil to supply minor elements to the plant. Plant uptake of a given nutrient depends on the activity of that element in the soil solution relative to other nutrients and the equilibrium relationship between ions in solution and solid phases (Khasawneh, 1971). Nutrient intensity and balance in the soil solution is a reflection of the existing equilibrium conditions. Three interacting factors have been defined which describe the relationship between ion uptake and the presence of ions in the soil solution (Khasawneh, 1971).

1. Intensity Factor: This is the activity (concentration) of a nutrient in solution which is a function of the chemical potential of the ion.

2. Capacity Factor: This describes the ability of the soil solution to replenish the concentration of a given nutrient in the soil solution after it has been depleted by plant uptake. This factor is a function of quantity, intensity, and the buffering capacity of the soil. Quantity, a measure of the amount of nutrients in reserve, and the buffering capacity, control the intensity of nutrients in the soil solution.

3. Relative Intensity Factor: This factor relates the effect of nutrient interactions on nutrient uptake. That is, the uptake of a nutrient may be controlled by the concentration of other nutrients.

In a field situation ion uptake is dependent on all three factors. In pot experiments where the amount of soil being cropped is limited, the most significant soil parameter usually becomes the capacity factor (Khasawneh, 1971).

Other variables influence the ability of the soil to supply adequate micronutrients besides the three factors previously noted. A well-known factor is the environmental influences on micronutrient uptake. Low soil temperature and cold, wet weather decrease the uptake of essential metal ions, especially iron and zinc (Viets, 1973). A lack of soil oxygen created by wet springs or excess irrigation will produce iron chlorosis (Lucas and Knezk, 1972). Lindsay and Thorne (1954) estimated that 50% of the lime induced chlorosis in Utah results from improper moisture control. Decreased solubility of soil zinc in cool weather produces zinc deficiencies (Bauer and Lindsay, 1965). Edwards and Kamprath (1974) found higher concentrations of zinc in the roots at low temperatures. This indicates low temperatures inhibit or slow down the translocation of zinc within the plant.

There are a variety of chemical factors which may affect the availability of micronutrients. In general, the availability of iron and zinc in soils is limited when the pH is greater than 7.0, and excess concentrations of phosphate, bicarbonates, and/or calcium salts (Brown et al., 1972) exist. Calcareous soils normally produce high concentrations of bicarbonate anion from the dissolution of alkaline earth carbonates by carbonic acid (Porter and Thorne, 1954). High concentrations of bicarbonate in the soil solution have been shown to interfere with iron absorption by plants (Brady, 1974; Lindsay and Thorne, 1953). Micronutrient interactions can take place both within the soil and the plant systems. An interaction occurs when one element exerts influence upon another in relation to plant growth (Olsen, 1972). Applied phosphorous reduces zinc uptake and translocation (Boawn and Brown, 1968). Pauli et al. (1968) added $CaCO_3$ in a sand culture experiment using isotopes of zinc and phosphorous. Dry weight yield and zinc concentration decreased in all plant parts. Singh (1976) produced a significant reduction in the iron concentration of a pea crop by the addition of $CaCO_3$. High phosphorous content also has a negative effect on the iron concentration within the plant. Iron movement is inhibited within the plant by excess phosphorous when the pH is above 7.0 (Olsen, 1972). Watanabe (1965) reported that the metabolic functioning of Fe in plants affects the supply of zinc. Applications of iron to soils where the supply of zinc is marginal may produce a zinc deficiency. Under these conditions, Jackson, Hay, and Moore (1967) found that an addition of zinc fertilizer increased the yield and produced plants with a lower iron concentration. Ambler et al. (1970) studied the effect of zinc on translocation of iron. Using iron-efficient plants, they determined that the reduction of ferric to ferrous iron was suppressed by zinc. Zinc was observed to interfere with the translocation of iron from the roots.

Detection of Micronutrient Deficiencies

The availability of iron and zinc in soils for plant uptake is a function of their solubility in a particular soil regime. High pH and high amounts of alkaline earth carbonates typify the calcareous bottomland soils found in southern Utah, particularly those soils deposited under Lake Bonneville. These soils have relatively low concentrations of plant available iron and zinc. Iron and zinc deficiencies in field corn can produce a vivid interveinal leaf chlorosis. For corn plants tissue concentrations of greater than 50 ppm iron and greater than 10 ppm Zn are generally considered to be sufficient for normal growth (Jones, 1967). Corn plants containing tissue concentrations of less than 9.0 ppm zinc and less than 56 ppm iron usually exhibit deficiency symptoms (Chapman, 1966).

Analysis of iron and zinc levels in calcareous soils is most successful using diethylenetriamine pentaacetic acid (DTPA) chelate extraction (Lindsay and Norvell, 1978). In California a critical level of 6 ppm DTPA extractable soil iron separated iron deficient from iron sufficient field grown plants at 11 of 13 locations (de Boer and Reisenauer, 1973). Using sorghum in a greenhouse study, de Boer and Reisenauer correctly predicted yield increases on 13 out of 14 soils using a critical level of 5 ppm DTPA extractable iron. A 10-year greenhouse study involving 77 soils from Colorado produced a soil iron critical level of 4.5 ppm for sorghum (Lindsay and Norvell, 1978). Lauer (1971) reported a high correlation ($r^2 = .97$) between plant zinc and DTPA-extractable soil levels of zinc. Brown et al. (1971) made a comparison study of zinc extractants. The extractants were DTPA, dithizone, 0.1N HCl and ethylenediamine tetraacetic acid (EDTA). The most successful extractant for predicting deficiencies was DTPA. Acid extractions of soil have proved to be less useful on calcareous soils because soil carbonates are dissolved which in turn releases unavailable iron (Trierweiler and Lindsay, 1969).

Chelate extractions were developed for calcareous soils. The advantage of chelate extractions is attributed to the use of a buffer in controlling the pH of the extracting solution to match the pH of the soil (Viets and Lindsay, 1973). Chelate extraction for micronutrients was developed by Lindsay et al. (1978) at Colorado State University. Lindsay maintains that chelates selectively extract free metal ions from the soil solution. The reduced free metal ion activity in the soil solution initiates an equilibrium reaction with ions on soil surfaces and with solid phases (Lindsay and Norvell, 1978).

Table 1 presents a summary of DTPA extractable soil iron and zinc critical levels established by researchers at different locations. All of the soils involved in these studies were calcareous. Critical levels predicted for soil iron ranges from 4.5-6.0 ppm for sorghum. The value representing the iron critical level for corn in Kansas was determined to be 2.0 ppm DTPA-extractable Fe. The critical level for soil zinc ranges from 0.6 - 0.8 ppm for corn. A

Table 1. Interpretive guide for DTPA-extractable iron and zinc critical levels.

Crop	Micro-nutrient	Location	Responsive	Probably responsive	Not responsive	Reference
			ppm			
Corn	Zn	California	0-0.3	0.3-0.6	0.6	Reisenauer and Quick (1971)
Corn	Fe	Kansas	0-2.0		2.0	Whitney et al. (1973)
Sorghum	Fe	Kansas	0-4.5		4.5	Whitney et al. (1973)
Field crops	Fe	Great Plains States	0-2.5	2.5-4.5	4.5	Mortvedt (1975)
Field crops	Zn	Great Plains States	0-0.5	0.5-1.0	1.0	Mortvedt (1975)
Sorghum	Fe	Colorado	0-2.5	2.5-4.5	4.5	Lindsay et al. (1978)
Sorghum	Zn	Colorado	0-0.6		0.6	Lindsay et al. (1978)
Sorghum	Fe	Field plots, California	0-6.0		6.0	de Boer et al. (1973)
Sorghum	Fe	Greenhouse pots	0-5.0		5.0	de Boer et al. (1973)

predicted value of 0.6 ppm DTPA-extractable zinc was reported for sorghum in Colorado.

Data Interpretation

Prediction and diagnosis of micro element deficiencies in crops is accomplished by using both soil tests and plant analysis. Soil tests must be correlated with crop response before they can be used for diagnosis. Yield response resulting from a given micronutrient addition confirms that the soil was deficient in that micronutrient providing all other nutrients are at adequate levels. Actual crop yields usually do not correlate well with soil tests since they contain many uncontrolled variables. The yield increase over a control is considered the best method for soil test correlations (Nelson and Anderson, 1977). Climatic variation, along with variation in soil texture, structure, CEC, and organic matter content will also influence the actual yield (Nelson and Anderson, 1977).

The effect of the extracting conditions in the laboratory has a significant influence on DTPA soil test values. Khan and Soltanpour (1976) demonstrated that the shape of the extraction vessel, type of shaker, shaker speed, and the time of shaking can all significantly influence DTPA soil test values. They reported a reduction in the iron critical level from 4.5 ppm to 3.3 ppm by using a slower shaking speed. Lindsay and Norvell (1978) presented a standardized procedure for DTPA chelate extractions. Procedures must be standardized to present valid correlations between laboratories. Precision of DTPA soil test values can be increased by controlling as many variables as possible.

The field plot situation presents many variables which can influence experimental micronutrient uptake values. Climate, irrigation practices, weed control, insect damage, and spatial variability of soil characteristics throughout the field can all influence the differences between the treatments. Greenhouse studies are one method of significantly reducing the number of complicating variables inherent in field plot studies. However, limitations also exist in greenhouse studies. Care must be exercised in the interpretation of greenhouse results when they are extrapolated to a field situation. Restricted root volume in greenhouse pots can accentuate crop response to a specific rate of fertilizer, while climatic and subsoil effects operating at the field level are neglected (Mortvedt, 1977).

Correlation of micronutrient concentrations in plant tissue with yield response has been less successful than correlation with soil test values (Watanabe et al., 1965; Lingle et al., 1963). This is ascribed to the dust contamination of plant samples which is difficult to control. Dust and surface contamination of plant samples is more of a problem with field studies than greenhouse experiments (Mortvedt, 1977). Since micronutrients are present in the plant in such small quantities, surface contamination of leaves can significantly increase apparent plant concentration values.

Correcting Micronutrient Deficiencies

One approach to correcting micronutrient deficiencies involves soil reclamation. For example, the reduction of pH on alkaline soils by applications of sulfuric acid increases the solubility of iron and manganese (Ryan et al., 1974). Soil application of sulfuric acid has been shown to increase iron and phosphorous availability in some calcareous soils, eliminating chlorosis in sorghum (Ryan et al., 1975). Wallace, Romney, and Alexander (1976) applied sulfur and sulfuric acid in bands to greenhouse pots where iron-inefficient plants were grown. Results showed that banding applications of sulfur or sulfuric acid may result in the correction of iron deficiency in some plant species (Wallace et al., 1976). Ryan and Stroehlin (1979) examined the effect of sulfuric acid treatments on the phosphorous availability of calcareous soils. In this study both extractable aluminum and iron increased with increasing amounts of sulfuric acid applied. Significant increase in available iron occurred once the buffering capacity of the soil was overcome by sulfuric acid applications (Ryan, 1974). The buffering capacity of the soil is the result of the presence of the basic constituents of the soil matrix, mainly carbonates. Ryan (1974) in a lab experiment applied acid to soils that had acid titratable basicity values ranging from 0.54 eq/kg to 2.48 eq/kg. Sulfuric acid applications effectively increased available iron concentrations only when they were applied at a rate that would neutralize 75% to 100% of the titratable bases. The ability of the soil to respond to acid treatment depended on the amount of reactive alkaline earth carbonates present in the system. On some soils the necessary acid application rate was too high to be a feasible alternative. Banding of sulfuric acid may be a method of circumventing the problem of trying to neutralize the entire root zone. At the present time, technology has not developed a practical method of banding sulfuric acid in a field situation.

The exact mechanism by which acid applications affect insoluble compounds of iron and manganese and the resulting soluble chemical forms is not completely known (Ryan et al., 1974). Acid applications have been reported to significantly reduce the bicarbonate concentration in the soil (Miyamoto et al., 1975; Lindsay and Thorne, 1954). This could presumably be the mechanism by which acid applications increase soil iron availability.

Crop species and varieties possess differential abilities to efficiently absorb and utilize micronutrients (Mortvedt, 1972). Clark and Brown (1974a) compiled a relative efficiency rating for mineral uptake by maize inbreds. Corn inbred Ysl/Ysl is the least efficient in utilizing iron and corn inbred WF9 was found to be most efficient. Clark and Brown (1974b) conducted nutrient solution studies to determine if iron uptake in corn plants is controlled inside or outside of the roots. They concluded that the iron efficiency in WF9 and Ysl/Ysl corn inbreds is controlled inside the root. Iron stressed WF9 produced more hydrogen ions in the nutrient solution and reduced more iron at the root surface than Ysl/Ysl. Wallace (1974) conducted a nutrient solution study using Ysl/Ysl and WF9 corn genotypes. He found a level of 10 ppm iron in the nutrient solution was necessary to obtain maximum yields for the iron-inefficient variety. Wallace also reported that both genotypes became iron deficient when $CaCO_3$ was in the nutrient solution and a low level of iron was applied.

Corn genotypes and their ability to efficiently utilize nutrients should be an important criteria for selecting the right varieties for a particular situation. This may be a better alternative than iron fertilization on calcareous soils where iron has such a limited solubility.

The use of iron chelates to correct iron chlorosis is not economically feasible for most field crops (Mortvedt, 1972). At the present time in Utah five pounds of iron chelate containing 6% iron costs $40.00. The final decision on how to correct the problem of lime-induced chlorosis should be based on a cost-benefit analysis. The ability of iron-efficient varieties to produce adequate yields versus the cost of applying iron chelate and using a higher yielding but iron-inefficient varieties should be considered.

Zinc is an effective micronutrient fertilizer when applied in sulfate, oxide or chelated forms (Murphy and Walsh, 1972). The zinc fertilizer can persist in a soil for years and stays available for a considerable length of time. Success with iron applications to the soil has been limited due to the reactions that occur between applied iron and the soil matrix. The problem of applied iron forming insoluble hydrous oxides has been partially solved by the use of iron chelates. Chelating agents form soluble iron complexes which prevent precipitation and leave iron in a plant available form. Iron is probably separated from the chelate molecule prior to plant absorption (Tiffin et al., 1961). In calcareous soils the stability of iron chelates is a function of the activity of calcium in the soil solution (Singh and Sinha, 1977). Lindsay and Norvell (1972) recorded a decrease in Fe-DTPA stability with rising pH. Decreasing solubility of iron with increasing pH allowed calcium to displace iron from Fe-DTPA. Metal chelates may require several weeks to equilibriate with ions in solution (Norvell and Lindsay, 1969). The iron released from iron chelates by displacement with calcium is partially available for plant absorption (Norvell and Lindsay, 1969). The ability of iron to remain in solution after separation from the chelate is dependent on the activity of iron in the soil solution in relation to concentration of other soluble cations.

In soils with a pH greater than 7.0, neither Fe-DTPA nor Fe-EDTA chelates can keep iron in solution. Iron is displaced from the chelate by calcium. Ethylenediamine di(o-hydroxyphenylacetic acid) (EDDHA) chelate can successfully keep iron in solution up to a pH value of 10.0 (Lindsay, 1974). Sequestrene 138 iron chelate fertilizer uses EDDHA as the chelate source. It is the most stable chelate fertilizer for calcareous soils.

Role of Chelation

According to Lindsay (1974), chelation of micronutrients is an essential process by which slightly soluble micronutrient cations are made available to plants. The solubility of inorganic iron is limited by the soil pH and is controlled largely by the solubility of iron oxides. Total soluble iron in soils must be at least 10^{-6} M to allow the mass flow of water to the roots to supply adequate iron. Equilibrium relationships from pH-solubility diagrams for iron oxides shcw that in the pH range of 7.0 to 8.0, total inorganic iron drops to approximately 10^{-11} M. In this pH range, the diffusion of iron cannot adequately supply the plants with iron. Other operable mechanisms must be used to explain the presence of adequate available iron in alkaline soils. Lindsay (1974) contends inorganic iron concentrations above the amount predicted from the solubility of iron oxides results from the presence of soluble iron complexes or chelating agents.

Chelating agents may originate as root exudates, products released from microbiological synthesis and decomposition of organic matter, or chelated fertilizers.

Chelation of zinc may also be an important phenomenon in soils where zinc is too insoluble to maintain an adequate supply of zinc to the plant.

MATERIALS AND METHODS

Sample Preparation

Prior to chemical analysis all soil samples were air dried, crushed with a wooden rolling pin, and screened through a 1-mm stainless steel sieve. The plant samples were thoroughly washed in a soap solution and rinsed in distilled water to remove any possible surface contamination. After oven drying for 24 hours, the plant samples were ground in a Wiley mill to pass a 20-mesh stainless steel screen. All glassware used in the analysis of plant and soil samples was acid washed to decrease the possibility of heavy metal contamination.

Soil Analysis

The soil reaction was measured with a glass pH electrode using a 1:1 ratio of soil to water. The cation exchange capacity was determined by sodium saturation (Chapman, 1965). Phosphorous concentrations were analyzed using the bicarbonate extraction method (Olsen and Dean, 1965). The water soluble ion concentrations were determined on the saturation extracts. The exchangeable amounts of sodium and potassium were calculated by subtraction of the water soluble ions from the ammonium acetate extractable ions (Pratt, 1965). Exchangeable calcium plus magnesium was determined by the difference between the amount of exchangeable sodium and potassium and the total cation exchange capacity. Calcium and magnesium cannot be determined directly by ammonium acetate extraction since ammonium acetate dissolves soil carbonates. The acid titratable basicity (ATB) values for the soils were determined by titration with 0.25 N NaOH, after the soil carbonates were dissolved, in a solution of excess 0.5 N HCl (Miyamoto et al., 1973). The calcium carbonate equivalent was calculated from the ATB values after Handbook 60 (U.S. Salinity Lab., 1954). Selected soil characteristics and properties of the five soils used in this study are given in Tables 2 and 3.

Iron and Zinc Extractions

The DTPA extractable Fe and Zn in the soils was determined using the procedure developed by Lindsay and Norvell (1978). The extracting solution consisted of a mixture of 0.005 M DTPA (diethylenetriamine-penta acetic acid), 0.01 M $CaCl_2$, and 0.1 M TEA (triethanolamine) adjusted to a pH of 7.3 with HCl.

Ten grams of air dry, sieved, soil was added to a 125 ml plastic Erlenmeyer flask containing 20 mls of the extracting solution. The flasks were covered with parafilm to reduce evaporation and shaken for two hours on an Eberbach horizontal shaker. The shaker speed was adjusted to 120 cycles/minute. The suspensions were filtered through Whatman #40 filter paper and the Fe and Zn concentrations in the filtrates were determined by a Varian Model 375 Atomic Absorption Spectrophotometer.

Table 2. Selected soil properties of the soils from Millard County, Utah.

Soil	Texture	pH	CEC	ECe	Titratable basicity ATB	$CaCO_3$ equivalent
			meq/100g	mmhos/cm	eq/Kg	%
Alldredge	silt loam	7.5	25.5	3.5	12.3	42.0
George	clay loam	8.3	21.0	2.5	3.5	10.8
Stewart	loam	8.0	14.4	1.1	2.5	7.7
Findleyson	sandy loam	7.8	14.9	2.1	3.0	9.7
Andersen	sandy loam	8.1	9.6	0.9	5.0	18.0

Table 3. Some chemical properties of the soils from Millard County, Utah.†

		H_2O Soluble			NH_4OAc		Exchange-able			Equivalent fraction of
Soil	$NaHCO_3P$	Na	K	SO_4	Na	K	Na	K	Ca+Mg	Ca+Mg
	ppm	meq/100g								
Alldredge	11	0.4	0.1	1.1	1.0	1.9	0.6	1.8	23.1	.91
George	41	0.7	0.3	0.6	0.9	3.2	0.2	2.9	17.9	.85
Stewart	21	0.1	0.1	0.9	0.1	1.7	<0.1	1.6	12.7	.88
Findleyson	18	0.1	0.1	6.0	0.4	3.0	0.3	2.9	8.0	.83
Andersen	11	0.1	0.1	1.0	0.2	1.6	0.1	1.5	11.7	.79

†All SAR values <1.0.

Plant Tissue Analysis

One gram samples of corn and oats were digested in 125 ml distillation flasks containing 30 ml of a 3.5:1 solution of nitric and perchloric acids. After digestion the samples were transferred to volumetric flasks and diluted to 50 mls with distilled water. The Fe and Zn concentrations were determined on the digestates using atomic absorption spectrophotometry.

Field Plot Study

In the spring of 1979, a field study was set up near Filmore in Millard County, Utah, in cooperation with a local farmer, and the USU Millard County extension agent. The field was leveled and first brought into production in 1978 and produced stunted corn with stripped foliage. Since the 1978 crop was not studied and problem areas were reported to occur only in spots, a split plot experimental design covering the entire length of the field was selected. This design usually loses precision in estimating main plot effects but precision for comparing the average effects of subplot treatments is increased.

The poor yield and stripping from the previous year was suspected to be either from an iron or zinc deficiency or both. A base treatment of N and P was applied to the entire study area (1.4 ha) at a rate of 100 lbs/Ac (112 Kg/ha) of P_2O_5 from a bulk blend of ammonium sulfate and treble super phosphate, 21-14-0. Four randomly applied mainplot treatments were applied in strips down the length of the field (381 meters). The mainplot treatments consisted of 4.5 metric tons of 95% H_2SO_4, 0.9 metric tons of 95% H_2SO_4, 1.68 metric tons of gypsum, and a check which contained the base treatment of N and P only. Utah Hybrid 544A corn seed was planted on 5/17/79 at a row spacing of 30 inches (11.8 cm). A buffer strip of 12 rows on each side of the experimental plots were also seeded with corn. The subplot treatments were applied by hand two weeks after planting. The subplot treatments were Fe chelate Sequestrene^R 138, zinc sulfate, Fe chelate plus zinc sulfate, and a check. The Fe chelate was applied at a rate of 5 lbs/Ac of Fe (5.6 Kg/ha) and the zinc sulfate was applied at a rate of 10 lbs/Ac of Zn (11.2 Kg/ha). The treatments were side dressed to every three corn rows in 200 foot (61 M) strips. The subplot treatments were randomly repeated across each mainplot in blocks and repeated three times down the length of the field at 200 foot intervals within each mainplot.

The field plots were harvested by hand on 9/29/79. Within each 200 foot subplot treatment, total yield was determined on four 20-foot (6.1 M) sample sections equally spaced down the length of each subplot. The middle row from each subplot treatment was sampled. Total yield was weighed using a 50 Kg hand scale and a canvas sling. Composite soil and leaf samples were removed from each of the yield sampling sections. Soil and plant samples were processed and analyzed using the procedure as previously described.

Greenhouse Study

Five soils representative of soils low in Fe and Zn from Millard County were selected for a greenhouse study (see Tables 2 and 3).

The bulk samples, collected in plastic lined garbage cans, were air dried, crushed, and screened through a 6 mm stainless steel screen. Thirty-six plastic pots were filled with 2.5 Kg of soil from each of the five bulk samples collected. The potted soils were equally divided into three groups and assigned one of three pretreatments. In the first group, 60 pots received no pretreatment. In the second group, 60 pots were fertilized with a solution of Fe chelate Sequestrene 138 and reagent grade $ZnSO_4 \cdot 7H_2O$ at a rate of 5 ppm each. After fertilization, the soils were removed from their pots, thoroughly mixed in a plastic tub, and then repotted. This second group was then subjected to an alternating wet and dry cycle. The third group of 60 pots was fertilized with 75 ppm P as $CaH_4(PO_4)_2 \cdot H_2O$ and 100 ppm N as NH_4NO_3 using reagent grade chemicals. This group of pots was cropped twice, once with corn and then with oats, as a pretreatment. The corn plants, thinned to 15 plants per pot, were grown for four weeks. An additional 200 ppm N was applied to each pot after two weeks of growth. At harvest time the corn plants were severed at the soil surface. The soil from each pot was air dried and mixed, the large roots removed, and repotted. Soil samples were taken from the repotted soils. All of the corn plants harvested were used for tissue analysis. Soil and plant samples were analyzed using the previously discussed procedures. Oats were then seeded in the same pots and thinned to 50 per pot. The pots were fertilized with 100 ppm N as needed. After five weeks the plants were harvested, processed, and analyzed by the same procedure as that for corn. To insure homogeneity of the soils studied, before the final study, the soils from each location were recombined, dried, thoroughly mixed, and sampled before they were repotted into the individual pots.

The pretreatments were designed to get a broader range of soil iron concentrations using only a limited number of soils. The need for a broader range of soil iron concentrations was an attempt to increase the accuracy of predicting a soil iron critical level for Utah using only five soils.

After the pretreatments were completed on all the soils, a randomized block experimental design was employed to measure potential yield increases in corn produced by the addition of Fe chelate. The randomized block design also reduced variability due to location within the greenhouse. The treatments were replicated three times with each of the five soils in each pretreatment group. The treatments were (1) five ppm Fe chelate 138 plus corn inbred WF9, (2) five ppm Fe chelate plus corn mutant Ysl/Ysl, (3) no Fe addition plus corn inbred WF9, (4) no Fe addition plus corn mutant Ysl/Ysl. The randomly assigned treatments were replicated three times in each block resulting in a total of 180 pots.

Phosphorous level in all pots was adjusted to 50 ppm P with $CaH_4(PO_4)_2 \cdot H_2O$. The pots were planted on 10/2/79 with five kernels per pot of the designated corn varieties. The soil was brought to field capacity by daily additions of distilled water to a predetermined weight. Eight days after emergence, the plants were thinned to three per pot. Every four days, 50 ppm N was applied as NH_4NO_3.

In addition, two applications of 50 ppm N were applied as NH_4SO_4 to insure the presence of adequate sulfur. Percent germination was recorded along with height growth at 12 and 24 days. The corn plants were harvested after five weeks. All of the harvested corn plants were analyzed for nutrient uptake as previously described. Prior to analysis of plant tissue, corn yields were determined by weighing plants oven dried overnight at 60°C. After removal of large roots and a thorough mixing, the soil in the pots was sampled. Table 4 summarizes the treatments in both the field and greenhouse studies.

Table 4. Outline of treatments used in study.

	Field Plots	
Soil location	Mainplots	Subplots within mainplots
Alldredge	N & P	Fe
	N & P & 1 ton H_2SO_4	Zn
	N & P & 5 tons H_2SO_4	Fe & Zn
	N & P & 1.8 tons Gypsum	Check

	Greenhouse	
Soil location	Pretreatment	Treatments
Alldredge	Fe & Zn incubation (all 5 soils)	WF9
George		WF9 & Fe 138
Stewart	Cropped twice (all 5 soils)	Ysl/Ysl
Findleyson	No pretreatment (all 5 soils)	Ysl/Ysl & Fe 138
Anderson		

RESULTS AND DISCUSSION

The soils used in this study are characterized in Tables 2 and 3. All of the soils were alkaline and only two of the five soils had pH values below 8.0. All of the soils were calcareous, with a calcium carbonate equivalent content ranging from 7.7% to 42%. The soil bicarbonate extractable phosphorous level was considered adequate in all cases. None of the soils, however, contained enough phosphorous to create a negative interaction with iron or zinc utilization by plants. The Alldredge soil, which was sampled from the field plot location in Millard County, had the highest concentration of soluble salts and the highest amount of titratable alkaline earth carbonates. The soluble salt concentration (ECe = 3.5 mmhos/cm) is of a level to produce yield reductions if salt sensitive plants are grown. The high concentration of titratable carbonates in the Alldredge soil (12.3 eq/Kg) would require a calculated 420 tons of sulfuric acid to neutralize an acre furrow slice. Using Ryan's (1974) recommendation to apply acid at a rate equivalent to 75% to 100% of the soil ATB value, the five ton/Ac (4.5 metric tons) application of sulfuric acid used as treatment in the field study cannot be considered as a viable treatment to increase the solubility of iron if the recommendation of Ryan is valid. The amount used in this study was that recommended by the local supplier. This rate of acid application can be regarded as a management amendment to increase the infiltration rate of the soil. The soils in Arizona, where an increase in iron, manganese, and phosphorous solubility was recorded by sulfuric acid applications, contained relatively small amounts of titratable carbonates. The ATB values for the calcareous Arizona soils ranged from 0.54 eq/Kg to 2.48 eq/Kg (Ryan, 1974) which is considerably lower than the 12.3 eq/Kg determined for the Alldredge soil.

Normally, for calcareous soils, the equivalent fraction of the cation exchange complex dominated by calcium and magnesium ranges from 0.90 to 0.98. The relatively low values of 0.79 to 0.91 (Table 3) obtained from the Millard County soils are explained by the relatively high concentrations of exchangeable potassium found in all of the soils (Table 3).

Field Plots Results

The statistical analysis of variance of the field plot samples produced generally low levels of significance (Table 5). The only exception was the F tests between the blocks. All of the variables between the blocks were significantly different at the 1% and 5% levels of probability. The significant differences between the blocks reflect the spatial variability of the soil in the field which may be due to the leveling of the field in 1978.

Stunted corn plants with stripped leaves occurred mainly in blocks II and III. In the control plots, DTPA extractable soil levels for iron and zinc were highly variable between the blocks. In block I, soil test values ranged from 6.0 to 12.0 ppm Fe and from 0.54 to 0.80 ppm Zn. In block II soil test values ranged from 1.7

Table 5. Field plot analysis of variance.

Source	Degrees of freedom	Mean Square				
		Yield	Soil Fe	Soil Zn	Plant Fe	Plant Zn
Blocks	2	5.67***	6.31***	.932***	.0817**	.611***
Mainplots†	3	.0497NS	.467NS	.0813*	.0622*	.0325**
Error A	6	.0664	.283	.0253	.149	.549
Subplots	3	.0924NS	.127*	.0157*	.0133*	.0118NS
Main X Sub	9	.0750NS	.0322NS	.0066NS	.0082NS	.0084NS
Error B	24	.0759	.0448	.0063	.0047	.0063
Sampling	144	.0609NS	.0120NS	.0068NS	.0037NS	.0081NS

†Mainplots not randomized
***Significant at 1% level
**Significant at 5% level
*Significant at 10% level
NSNot significant

to 4.1 ppm Fe and from 0.30 to 0.50 ppm Zn. In block III soil test values ranged from 2.4 to 4.0 ppm Fe and from 0.30 to 0.50 ppm Zn. Soil iron and zinc levels in blocks II and III are generally below the critical levels suggested by other workers (Table 1). Subplot applications of iron chelate or zinc sulfate did not significantly increase yields. Although the subplot treatments produced significant differences in the soil iron and zinc concentrations at the 10% level of probability, the subplot fertilizer applications did not increase soil Fe and Zn concentrations above the critical level of 4.5 to 6.0 ppm Fe and 0.60 ppm Zn. Theoretically, iron and zinc applications if applied at a rate high enough to increase soil values above the critical levels would produce a significant yield increase over the control subplot treatment. The data suggest that the iron and zinc applications were essentially rendered unavailable by reactions of the applied micronutrient with the highly calcareous soil matrix.

The mainplot treatments (Table 5) did not significantly affect either the yield or the soil iron level. The calculated F test values indicated a low level of significance (10%) between mainplot treatments and plant Fe, Zn and soil Zn. The validity of the mainplot treatment effects can be questioned because they were not replicated. Treatments were applied in strips due to the large size of the field. On a large area, replicating the mainplot treatments randomly throughout the field by tractor application were considered to be impractical.

Mainplot and subplot interactions, and sampling differences for all variables were also found to be nonsignificant (Table 5).

Linear correlation coefficients were determined for all of the variables used in the field plot study (Table 6). All of the correlation coefficients were medium to low, with one exception. A moderately high correlation, $r^2 = .76$, existed between the soil iron level and the soil zinc level. This relationship implies soil iron and soil zinc availability increased and decreased together throughout the sampling area. The regression coefficient, r^2, for the soil iron and soil zinc was .577. Therefore 58% of the time a change in the soil iron concentration occurred with a similar change in the soil

Table 6. Correlation matrix for the field plot data.

	Yield	Soil Fe	Soil Zn	Plant Fe	Plant Zn
Yield	1.0	.54	.50	.35	.55
Soil Fe		1.00	.76	.34	.59
Soil Zn			1.00	.29	.63
Plant Fe				1.00	.44
Plant Zn					1.00

zinc concentration. This relationship suggests that the soil factors limiting iron solubility was also limiting zinc solubility.

The relationship between yield and soil iron, yield and soil zinc, yield and plant zinc, soil iron and plant sinc, soil zinc and plant zinc all produced medium correlations (Table 6). These correlations suggest that there is a trend towards a significant relationship but from 75% to 61% of the variability is left unexplained.

The low correlation coefficients between plant iron concentrations and all variables supports the supposition that the critical level of soil iron is best established when yield is correlated with extractable soil iron rather than the iron content of the plant.

Table 7 presents a summary of mean values for all of the variables measured in the field plot experiment. The mean values are first listed by location or block and then by the type of mainplot treatment applied. The yield in block I had a significantly higher yield mean than blocks II and III. Extrapolating these sample means to a

Table 7. Mean values from field plots in Filmore, Utah.

	Yield kg/20'	Soil Fe	Soil Zn	Plant Fe	Plant Zn
		ppm			
Block			Block Means		
I	23.1	14.1	.66	53.7	12.4
II	7.0	3.14	.41	41.8	7.4
III	11.0	3.37	.39	50.5	8.4
Mainplot			Mainplot Means		
Control	13.6	5.1	.47	44.7	9.27
5 ton H_2SO_4	14.0	5.7	.50	48.0	9.5
1 ton H_2SO_4	13.75	12.4	.55	51.9	9.8
Gypsum	13.62	4.22	.43	49.0	9.1

hectare basis produces a yield of 19,895 Kg/ha for block I and yields of 6,102 Kg/ha and 9,495 Kg/ha for blocks II and III, respectively. Standard chemical analysis conducted on soil samples collected from the different blocks produced similar results with the exception of DTPA extractable iron and zinc. Soil reaction, soluble salt concentrations, ATB values, phosphorous and nitrogen levels were similar in all of the blocks, whereas the mean values for the soil iron concentration in blocks II and III were below the critical level established by other researchers. In these same blocks, II and III, the soil zinc block means indicated that the blocks had only a marginal amount of DTPA extractable zinc available for plant uptake. These predicted deficiencies can also be noted by examining the plant iron and zinc means for each of the blocks (Table 7) and comparing them to the predicted critical levels. In blocks II and III the plant iron concentration mean is 50 ppm or less where the plant iron critical level is considered to be from 50 to 56 ppm. Correspondingly, the plant zinc concentration mean is less than 9.0 ppm which is the critical level for plant zinc.

Comparison of mean values from the different mainplots do not show any statistically significant differences. Mean values do show predictable differences. The application of gypsum as a mainplot treatment produced the lowest mean values for soil iron (4.2 ppm) and soil zinc (0.43 ppm). This soil already contains excess gypsum. The source for the gypsum application was a hill less than a half mile away from the field. The sulfuric acid mainplots produced the highest mean values for soil iron, soil zinc and yield. Interpretations cannot be made from these data since the differences are not statistically significant and mainplots were not replicated.

The large LSD values for the field plot analysis can be attributed to the large error mean square obtained from the analysis of variance. A large error term in the analysis of variance indicates a large amount of unexplained variability exists in the experiment. One of the assumptions in applying the analysis of variance is that the variances between samples (or blocks) are homogenous. A large error term may result when there is a large amount of variability between the blocks.

Experimental variability. To be of maximum usefulness field plot studies should be repeated for several years to provide accurate prediction of treatment effects. In a single year field plot study, as the one reported, location and climate effects cannot be fully assessed. In addition, the author noted several sources of possible yield variation that were not controlled. Inexperience on the author's part and a lack of cooperation at the field level introduced additional sources of variation into the statistical analysis of the field plot data. Examples are given below.

The statistical analysis of variance of the data was confounded by the lack of cultural field practices which is an everpresent hazard of cooperative field plot studies. Herbicide was applied only once, three weeks after planting. Weeds such as morning glory and Jerusalem thistles were prevalent across the ridges and furrows. At harvest, the weeds had to be separated from the corn plants before the yields could be measured.

A timing problem prevented the mainplot applications of sulfuric acid from being applied until several days after the corn was planted. In addition, the acid truck was able to deliver only one ton per trip across the field. Serious wheel compaction and rutting occurred on the acid mainplots as the result of repeated trips to apply the required treatment. Seedling germination and emergence were limited in long strips in the middle of the field where the soil conditions were the most marginal. Five yield sampling sections within the acid mainplots had a zero yield.

Examination of the sulfuric acid mainplots several weeks after the date of application revealed large white spots on the soil surface at regular intervals down the length of the field. Although the author did not witness the acid application, the powdery nature and the regularity of the white spots suggest the acid may have been applied in spurts as the truck moved down the field.

The availability and amount of zinc in the fertilizer source for the field plot study is also questionable. The fertilizer was a donation by the Millard County Extension Agent through a local fertilizer company. The fertilizer was reported to contain 8% available zinc as zinc sulfate. After the subplot treatments were applied a sample of the fertilizer was brought to the laboratory and analyzed. The zinc fertilizer had a metallic appearance suggesting a by-product of a mining operation. The fertilizer was digested in the laboratory using nitric and perchloric acids. Total zinc in the fertilizer samples was found to range from 5% to 7%. These data suggest that it is highly improbable that the zinc treatment supplied the amount calculated for the treatment or indeed, was available to the plant. Since no treatment using only $ZnSO_4$ was made, no comparison can be made of the value of the zinc fertilizer material. This same fertilizer material also contained 20% total iron.

Greenhouse Study

Statistical analysis of variance of the greenhouse samples, in most cases, produced highly significant results (Table 8). A majority of the results, however, were expected. An unexpected result was the

Table 8. Greenhouse analysis of variance.

Source	Degrees of freedom	Mean Square Yield	Soil Fe	Plant Fe
Blocks	2	1,165,512***	4.3700**	†
Soil	4	5,866,663***	65.4000***	364.30***
Iron fertilization	1	3,889,620***	196.5000***	2509.00***
Variety	1	76,880 NS	0.1805 NS	4824.00***
Pretreatment	2	5,091,707***	53.8000***	58.86 NS
Soils x Iron	4	358,656***	5.3200***	11.01 NS
Soils x Variety	4	209,057**	0.3540 NS	169.80**
Soils x Pretreatment	8	774,446***	3.5400**	65.24 NS
Iron x Variety	1	3,152,180***	0.0530 NS	232.10***
Iron x Pretreatment	2	38,806 NS	0.7690 NS	14.06 NS
Variety x Pretreatment	2	646,326***	0.1540 NS	39.26 NS
S x I x V	4	265,416***	0.5750 NS	
S x I x P	8	118,219 NS	0.6870 NS	
S x V x P	8	139,594 NS	0.4120 NS	
I x V x P	2	75,860 NS	0.0474 NS	
S x I x V x P	8	89,173 NS	0.2790 NS	
Error	118	76,791	0.5330	46.55

† Due to the small plant yields, block plant samples were combined for tissue analysis. The three and four way interactions were combined and used as the error term for Plant Fe. Degrees of freedom = 30.

*** Significant at 1% probability.

** Significant at 5% probability.

NS Not significant.

lack of significant yield differences between the corn varieties. Although the two varieties, Fe-inefficient Ysl/Ysl and Fe-efficient WF9, abosrbed highly significant different amounts of iron, their yields were similar. The lack of yield differences between the varieties may have resulted from the slower germination and emergence of the iron-efficient variety in the greenhouse. The iron-efficient variety was observed to germinate and emerge 5 to 7 days slower than the iron-inefficient variety. Total germination was recorded after 12 days. The iron-inefficient germination was 93% compared to a germination value of 87% for the iron-efficient variety. Clark and Brown (1974) compared the relative efficiency of corn inbred WF9 to corn mutant Ysl/Ysl in a greenhouse project using low iron calcareous soils. They found that top dry matter yields of the iron-inefficient Ysl/Ysl were 64% less than the iron-efficient WF9 variety when the plants were grown for 21 days.

The pretreatments produced a significant effect, at the 1% level of probability, on the soil iron level (Table 8). This indicates the soil pretreatment accomplished the objective of obtaining a broader range of soil iron concentrations using a limited number of soils.

Calculation of r values for the greenhouse data resulted in correlation coefficients which produced the expected relationships (Table 9). A very low correlation existed between soil Fe, plant Fe and yield with the iron-efficient WF9 variety. Medium correlation existed between soil Fe, plant Fe and yield with the iron-inefficient Ysl/Ysl variety. The soil iron concentration had very little effect

Table 9. Correlation matrix from the greenhouse experiment.

	WF9			Ys1/Ys1		
	Yield	Soil Fe	Plant Fe	Yield	Soil Fe	Plant Fe
Yield	1.0	0.26	0.15	1.0	0.56	0.42
Soil Fe		1.00	0.50		1.00	0.48
Plant Fe			1.00			1.00

on the growth of the iron-efficient variety although the growth of the iron-inefficient variety was significantly influenced by the soil iron concentration. Both varieties produced medium correlations between soil iron and plant iron.

Zinc was not a limiting factor in plant growth in the greenhouse study (Table 10). The first, second and third croppings all contain adequate zinc when compared to the plant critical level of 9.0 ppm Zn. The iron-inefficient variety in the third cropping extracted an insufficient amount of iron from all of the soils.

The soil zinc concentrations are listed in Table 11 by pretreatment after the final crop was harvested. Upon comparison to established DTPA extractable Zn critical levels (Table 1), only the Alldredge soil (A1), which was cropped twice as a pretreatment, contains a marginal amount of zinc.

Critical level. The effectiveness of the DTPA soil test for separating soils based on yield response to iron fertilization is summarized in Fig. 1 and 2. The data in each figure are from 40 pots of the greenhouse experiment. A significant yield response to iron

Table 10. Greenhouse sample means for plant tissue concentrations.

Soil	1st crop Corn Fe	1st crop Corn Zn	2nd crop Oats Fe	2nd crop Oats Zn	3rd crop Ysl/Ysl Fe	3rd crop Ysl/Ysl Zn	3rd crop WF9 Fe	3rd crop WF9 Zn
	ppm							
Al	55	23	50	19	34	11	51	14
S	79	25	64	19	32	20	74	19
G	60	27	54	25	36	27	52	26
An	60	25	55	22	33	26	69	23
F	72	25	57	17	45	22	62	25

Table 11. Sample means for soil Zn concentration after final crop.

Soil	Cropped twice Ysl/Ysl & WF9	No pretreatment Ysl/Ysl & WF9	Fe and Zn fertilization Ysl/Ysl & WF9
	ppm		
Al	.41	.65	1.5
S	.61	.69	1.9
G	.86	1.3	3.1
An	.86	.56	1.9
F	.54	.50	2.1

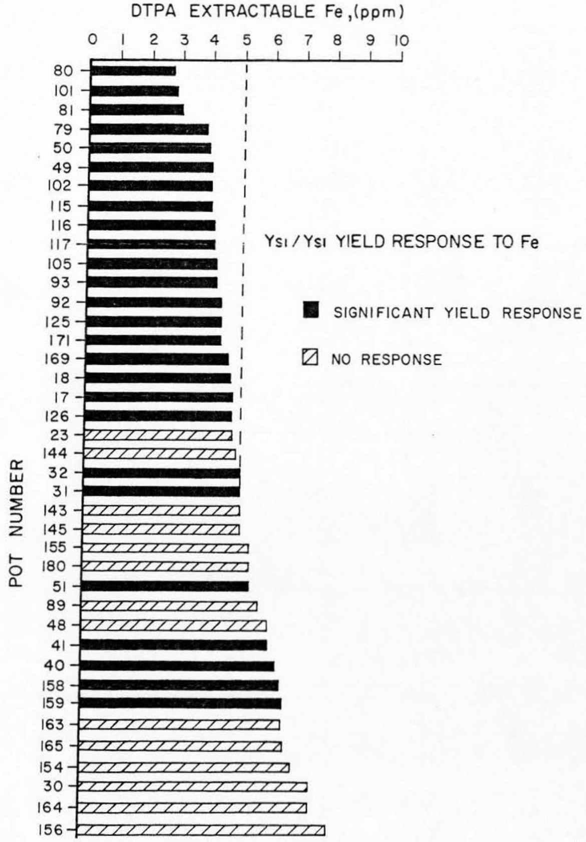

Fig. 1. Ysl/Ysl yield response to applied iron.

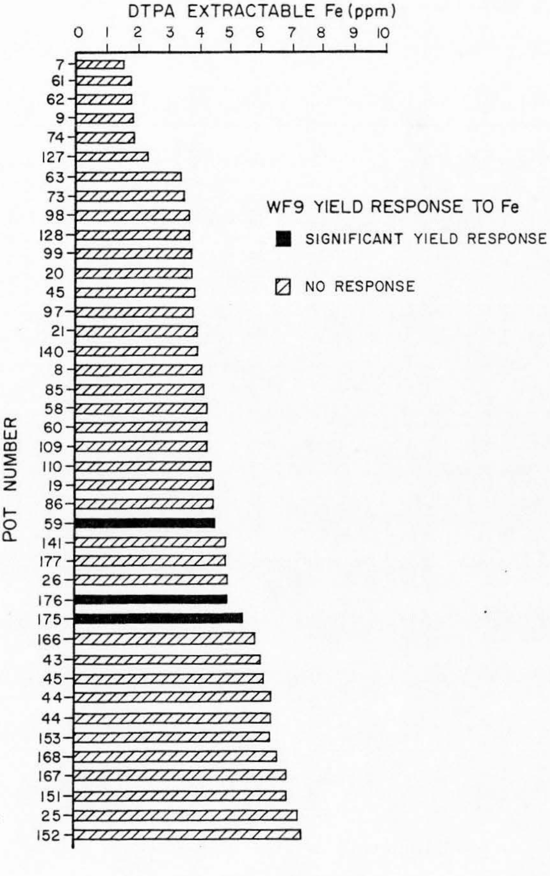

Fig. 2. WF9 yield response to applied iron.

fertilization was determined by an LSD test at the 95% level of confidence. Dry weight yields, yield increases, soil iron and plant iron levels are listed for all of the greenhouse pots in Appendix B. The black bars represent pots that produced a significant yield response to iron fertilization indicating that they were deficient in iron. The cross-hatched bars represent pots that did not respond to iron fertilization.

The iron-inefficient variety is represented in Fig. 1. Generally soils which contained greater than about 5 ppm DTPA extractable iron did not respond to applied iron. The critical level of DTPA extractable iron, determined for the calcareous soils of Millard County, was estimated to be 5 ppm. Five pots of the iron-inefficient variety which contained greater than 5 ppm iron did respond to applied iron (Fig. 1). All five of the pots were the Findleyson soil. The variable response above the projected critical level is not uncommon and can be contributed to the uniqueness of the soil and to the inherent variability of natural processes. The iron-efficient variety is represented in Fig. 2. Only three of the pots produced a yield response to applied iron. All of the pots were the Findleyson soil. They responded within the estimated critical level range. Soils with iron concentrations greater than 5 ppm are not expected to show a yield response to iron fertilization.

In Appendix A self-explanatory photographs show the response of iron-efficient and iron-inefficient corn varieties to iron treatment in the greenhouse.

SUMMARY AND CONCLUSIONS

Field Plot Study

1. Soil applications of Fe chelate 138 at 5 lbs/Ac of Fe were ineffective in increasing soil iron availability in the field plot study. As a result, yield increases were not observed.

2. Soil applications of Zn at 10 lbs/Ac did not produce a response. Yield increases were not recorded from the application of zinc.

3. The soils at the field plot location contained a limiting amount of iron and zinc on approximately two-thirds of the test area.

4. The spatial variability of iron and zinc availability in the field suggests that the leveling of the field in 1978 may be a major factor in the iron and zinc levels. Higher iron and zinc concentrations in block I suggest that this block may contain most of the top soil.

5. The sensitivity of corn to iron and zinc deficiencies and the concentration of soluble salts present in the field plot soil combined to produce stunted and chlorotic plants on two-thirds of the area.

6. Surface application of sulfuric acid at rates of 1 ton and 5 tons per acre on soils that contain large amounts of titratable bases was not effective at increasing the availability of micronutrients as measured by extraction from the soil and by yield. High rates of acid application to soils that contain a large amount of carbonates, such as the field plot, may significantly increase the

concentration of soluble salts above the tolerance level for most crops.

7. Data suggest that rates of applied Fe chelate in excess of 10 lbs/Ac of Fe appear necessary on the Alldredge soil to increase the availability of Fe. This is not economically feasible for most field crops due to the high cost of Fe chelate. At current prices in Utah, an application rate of 10 lbs/Ac would cost over $1600.00/Ac.

8. The lack of technical advice on implementation of the field plot study was considered a major barrier in achieving the desired results.

9. The zinc fertilizer source used should be rated against reagent grade $ZnSO_4$ to determine its effectiveness as a source of available zinc.

10. A crop less sensitive to micronutrient deficiencies and soluble salts such as barley could be a viable alternative to assure an economic return.

11. The development of a banding technique to apply sulfuric acid in the root zone and creating a micro-environment where the bases are buffered could temporarily increase the availability of iron.

12. Alternative methods of overcoming the problems of growing crops where Fe and Zn may be deficient should be more fully investigated:

a. The ability of iron and zinc efficient varieties to produce adequate yields under the environmental conditions found in Utah.

b. The response of field corn to foliar applications of Fe chelate and $ZnSO_4$.

Greenhouse

13. A high ATB content in the greenhouse soils required a correspondingly higher rate of Fe chelate application to produce a significant yield response.

14. The Alldredge soil in the greenhouse did not respond to 10 lbs/Ac (5 ppm) Fe chelate. The Alldredge soil which was fertilized with Fe chelate as a pretreatment failed to produce a significant yield response. To these pots, a rate of 10 lbs/Ac was applied twice.

15. The soil pretreatments accomplished the objective of producing a more variable range of soil iron concentrations. This simulates the use of a large number of calcareous soils which is necessary to accurately predict a critical level.

16. A soil iron critical level of 5 ppm Fe is proposed for calcareous soils in Utah.

17. Evidence was inconclusive as to the ability of Fe efficient WF9 inbred to produce higher yields than the iron inefficient Ys1/Ys1 variety under short term growth conditions in the greenhouse.

18. Additional studies are needed to compare the cost benefit ratio of using Fe efficient compared to Fe inefficient varieties.

19. The greenhouse study should be continued to obtain yield response data on many soils throughout Utah to increase the accuracy of the predicted critical level.

20. Greenhouse results suggest that the efficiency of the variety to utilize soil iron does not influence the ability of the plant to extract soil zinc. Zinc-efficient and zinc-inefficient varieties should also be incorporated into the greenhouse and field plot studies.

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APPENDICES

Appendix A

Fig. 3. Response to Fe fertilization on the Findleyson soil with the iron-inefficient variety of corn. Both pots were cropped twice as a pretreatment.

Fig. 4. Iron-inefficient corn response to the pretreatments on the Stewart soil. Pot on the left was cropped twice as a pre-treatment. The middle pot did not receive a pretreatment. The pot on the right was fertilized with iron and zinc.

Fig. 5. Lack of response to the pretreatments on the Alldredge soil with the Fe-inefficient variety. All pots contained iron concentrations below the critical level.

Fig. 6. The iron-efficient variety failed to respond to an increasing soil iron concentration on the George soil. The pot on the right contains the highest concentration of DTPA extractable Fe.

Fig. 7. A comparison of the iron-efficient and iron-inefficient corn varieties on the Stewart soil which was cropped twice as a pretreatment. Iron cheletes were not added to either pot. The iron-inefficient variety is on the left.

Appendix B

Table 12. Individual data from greenhouse pots.

Pot	Block	Soil treatment and variety		Yield	Yield increase†	Soil Fe	Plant Fe	Pre-treatment
				-------mg-------		----ppm----		
1	II	Al+Fe	Ysl/Ysl	610	210	3.9	49	Cropped
2	III	Al+Fe	Ysl/Ysl	610	270	3.9	49	"
3	I	Al+Fe	Ysl/Ysl	320	0	3.1	49	"
4	I	Al+Fe	WF9	480	10	2.9	59	Cropped
5	III	Al+Fe	WF9	350	0	2.9	59	"
6	II	Al+Fe	WF9	630	160	5.3	59	"
7	I	Al	WF9	470	-	1.6	51	Cropped
8	II	Al	WF9	470	-	4.2	51	"
9	III	Al	WF9	500	-	2.9	51	"
10	II	Al	Ysl/Ysl	400	-	3.9	34	Cropped
11	III	Al	Ysl/Ysl	340	-	1.8	34	"
12	I	Al	Ysl/Ysl	380	-	2.9	34	"
13	III	G+Fe	WF9	750	0	6.7	62	Cropped
14	I	G+Fe	WF9	1000	0	6.0	62	"
15	II	G+Fe	WF9	1080	0	8.9	62	"
16	III	G+Fe	Ysl/Ysl	890	240	8.1	49	Cropped
17	I	G+Fe	Ysl/Ysl	1110	830**	7.8	49	"
18	II	G+Fe	Ysl/Ysl	930	470**	6.6	49	"
19	II	G	WF9	1120	-	4.5	52	Cropped
20	I	G	WF9	1000	-	3.8	52	"
21	III	G	WF9	930	-	4.0	52	"
22	II	G	Ysi	500	-	4.7	36	Cropped
23	III	G	Ysi	650	-	4.8	36	"
24	I	G	Ysi	280	-	4.8	36	"
25	II	S	WF9	890	-	7.3	74	Cropped
26	III	S	WF9	290	-	4.9	74	"
27	I	S	WF9	760	-	6.3	74	"
28	II	S	Ysl/Ysl	570	-	5.0	32	Cropped
29	III	S	Ysl/Ysl	510	-	5.1	32	"
30	I	S	Ysl/Ysl	930	-	7.4	32	"
31	II	S+Fe	Ysl/Ysl	1110	640**	9.7	46	Cropped
32	III	S+Fe	Ysl/Ysl	1020	510**	7.0	46	"
33	I	S+Fe	Ysl/Ysl	1270	340	8.6	46	"

Table 12. Continued.

Pot	Block	Soil treatment and variety		Yield	Yield increase†	Soil Fe	Plant Fe	Pre-treatment
				-------mg-------		----ppm----		
34	II	S+Fe	WF9	850	0	8.1	89	Cropped
35	III	S+Fe	WF9	460	170	9.0	89	"
36	I	S+Fe	WF9	590	0	9.3	89	"
37	II	An+Fe	WF9	910	0	8.2	73	Cropped
38	III	An+Fe	WF9	810	0	7.1	73	"
39	I	An+Fe	WF9	1130	0	7.9	73	"
40	II	An+Fe	Ys1/Ys1	2340	1460**	8.9	59	Cropped
41	III	An+Fe	Ys1/Ys1	1260	570**	8.3	59	"
42	I	An+Fe	Ys1/Ys1	1360	180	8.2	59	"
43	II	An	WF9	1870	-	6.1	69	Cropped
44	III	An	WF9	1250	-	6.4	69	"
45	I	An	WF9	1700	-	6.2	69	"
46	II	An	Ys1/Ys1	880	-	6.3	33	Cropped
47	III	An	Ys1/Ys1	690	-	6.5	33	"
48	I	An	Ys1/Ys1	1180	-	6.0	33	"
49	III	F+Fe	Ys1/Ys1	1430	1100**	6.1	56	Cropped
50	I	F+Fe	Ys1/Ys1	1600	1270**	7.1	56	"
51	II	F+Fe	Ys1/Ys1	1940	1360**	6.8	56	"
52	III	F+Fe	WF9	1450	830**	5.6	69	Cropped
53	I	F+Fe	WF9	1660	260	6.3	69	"
54	II	F+Fe	WF9	1690	220	7.0	69	"
55	I	F	Ys1/Ys1	330	-	3.9	45	Cropped
56	III	F	Ys1/Ys1	330	-	4.0	45	"
57	II	F	Ys1/Ys1	580	-	5.4	45	"
58	II	F	WF9	1470	-	4.3	62	Cropped
59	III	F	WF9	620	-	4.5	62	"
60	I	F	WF9	1400	-	4.3	62	"
61	III	Al	WF9	400	-	1.8	49	None
62	I	Al	WF9	890	-	1.8	49	"
63	II	Al	WF9	1000	-	3.4	49	"
64	III	Al	Ys1/Ys1	380	-	2.2	27	None
65	I	Al	Ys1/Ys1	620	-	1.8	27	"
66	II	Al	Ys1/Ys1	660	-	3.5	27	"
67	III	Al+Fe	WF9	500	100	3.4	56	None
70	I	Al+Fe	WF9	720	0	2.4	56	"
69	II	Al+Fe	WF9	870	0	4.6	56	"

Table 12. Continued.

Pot	Block	Soil treatment and variety		Yield	Yield increase†	Soil Fe	Plant Fe	Pre-treatment
				------mg--------		----ppm----		
68	III	Al+Fe	Ysl/Ysl	560	180	2.5	38	None
71	I	Al+Fe	Ysl/Ysl	1190	570	3.1	38	"
72	II	Al+Fe	Ysl/Ysl	790	140	2.9	38	"
73	II	G	WF9	840	–	3.5	61	None
74	I	G	WF9	1380	–	2.9		"
75	III	G	WF9	1450	–	3.9		"
76	III	G	Ysl/Ysl	350	–	3.0	45	None
77	I	G	Ysl/Ysl	300	–	2.7		"
78	II	G	Ysl/Ysl	280	–	3.8		"
79	II	G+Fe	Ysl/Ysl	810	530**	6.1	61	None
80	I	G+Fe	Ysl/Ysl	890	590**	6.5		"
81	III	G+Fe	Ysl/Ysl	970	620**	6.6		"
82	II	G+Fe	WF9	860	20	6.6	64	None
83	I	G+Fe	WF9	1310	0	6.5		"
84	III	G+Fe	WF9	590	0	7.3		"
85	III	S	WF9	540	–	4.2	65	None
86	I	S	WF9	480	–	4.5		"
87	II	S	WF9	660	–	4.5		"
88	II	S	Ysl/Ysl	450	–	4.2	36	None
89	III	S	Ysl/Ysl	600	–	5.7		"
90	I	S	Ysl/Ysl	750	–	4.4		"
91	III	S+Fe	Ysl/Ysl	710	110	5.8	65	None
92	I	S+Fe	Ysl/Ysl	1100	450**	7.1		"
93	II	S+Fe	Ysl/Ysl	1350	900**	4.7		"
94	III	S+Fe	WF9	580	40	6.7	69	None
95	I	S+Fe	WF9	700	220	7.0		"
96	II	S+Fe	WF9	490	0	6.8		"
97	II	An	WF9	640	–	3.9	69	None
98	I	An	WF9	1730	–	3.7		"
99	III	An	WF9	920	–	3.8		"
100	II	An	Ysl/Ysl	880	–	4.0	33	None
103	I	An	Ysl/Ysl	860	–	2.8		"
104	III	An	Ysl/Ysl	670	–	4.2		"
101	I	An+Fe	Ysl/Ysl	2340	1480**	6.1	56	None
102	II	An+Fe	Ysl/Ysl	1730	850**	5.3		"
105	III	An+Fe	Ysl/Ysl	1630	960**	5.7		"

Table 12. Continued.

Pot	Block	Soil treatment and variety		Yield	Yield increase[†]	Soil Fe	Plant Fe	Pre-treatment
				------mg--------		----ppm----		
106	II	An+Fe	WF9	840	200	5.7	83	None
107	III	An+Fe	WF9	1260	340	5.8		"
108	I	An+Fe	WF9	1510	220	3.2		"
109	III	F	WF9	1000	-	4.3	65	None
110	II	F	WF9	830	-	4.4		"
111	I	F	WF9	1010	-	3.8		"
112	I	F	Ysl/Ysl	850	-	4.0	43	None
113	II	F	Ysl/Ysl	760	-	4.1		"
114	III	F	Ysl/Ysl	380	-	4.1		"
115	I	F+Fe	Ysl/Ysl	1490	640**	6.4	70	None
116	III	F+Fe	Ysl/Ysl	1080	700**	6.4		"
117	II	F+Fe	Ysl/Ysl	1370	610**	6.3		"
118	III	F+Fe	WF9	670	0	6.4	71	None
119	II	F+Fe	WF9	1090	280	6.5		"
120	I	F+Fe	WF9	1000	0	5.4		"
123	III	Al+Fe	WF9	1000	180	5.7	62	Fertilized
122	I	Al+Fe	WF9	1280	370	4.8		"
124	II	Al+Fe	WF9	1370	370	4.4		"
121	III	Al+Fe	Ysl/Ysl	1050	410	5.0	49	Fertilized
125	II	Al+Fe	Ysl/Ysl	1720	780**	5.7		"
126	I	Al+Fe	Ysl/Ysl	1800	700**	4.5		"
127	III	Al	WF9	820	-	2.4	50	Fertilized
128	II	Al	WF9	1000	-	3.7		"
129	I	Al	WF9	910	-	3.7		"
130	I	Al	Ysl/Ysl	1100	-	3.5	33	Fertilized
131	III	Al	Ysl/Ysl	840	-	2.9		"
132	II	Al	Ysl/Ysl	940	-	2.6		"
133	II	G+Fe	WF9	660	0	8.6	64	Fertilized
134	III	G+Fe	WF9	480	0	8.5		"
135	I	G+Fe	WF9	760	0	7.9		"
136	II	G+Fe	Ysl/Ysl	600	30	7.5	36	Fertilized
137	III	G+Fe	Ysl/Ysl	680	0	7.8		"
138	I	G+Fe	Ysl/Ysl	1290	0	8.2		"
139	II	G	WF9	1050	-	4.3	32	Fertilized
140	I	G	WF9	610	-	4.0		"
141	III	G	WF9	690	-	4.9		"

Table 12. Continued.

Pot	Block	Soil treatment and variety		Yield	Yield increase[†]	Soil Fe	Plant Fe	Pre-treatment
				------mg--------		----ppm----		
143	I	G	Ysl/Ysl	1550	-	5.1	20	Fertilized
144	III	G	Ysl/Ysl	880	-	4.9		"
145	II	G	Ysl/Ysl	570	-	5.1		"
142	I	S+Fe	WF9	1420	400	9.9	67	Fertilized
146	II	S+Fe	WF9	1000	0	8.9		"
147	III	S+Fe	WF9	590	0	8.7		"
148	II	S+Fe	Ysl/Ysl	1110	0	9.6	51	Fertilized
149	I	S+Fe	Ysl/Ysl	1290	110	9.4		"
150	III	S+Fe	Ysl/Ysl	990	0	8.0		"
151	II	S	WF9	670	-	6.9	58	Fertilized
152	I	S	WF9	830	-	7.4		"
153	III	S	WF9	790	-	6.4		"
154	III	S	Ysl/Ysl	1210	-	6.8	25	Fertilized
155	I	S	Ysl/Ysl	1180	-	5.4		"
156	II	S	Ysl/Ysl	1170	-	8.0		"
157	II	An+Fe	Ysl/Ysl	3080	710**	9.2	51	Fertilized
158	I	An+Fe	Ysl/Ysl	3530	1750**	9.2		"
159	III	An+Fe	Ysl/Ysl	2620	940**	8.1		"
160	I	An+Fe	WF9	2840	50	7.7	71	Fertilized
161	III	An+Fe	WF9	1960	0	5.8		"
162	II	An+Fe	WF9	1650	0	7.7		"
163	I	An	Ysl/Ysl	1780	-	6.4	45	Fertilized
164	II	An	Ysl/Ysl	2370	-	7.4		"
165	III	An	Ysl/Ysl	1680	-	6.5		"
166	III	An	WF9	2330	-	5.8	61	Fertilized
167	II	An	WF9	2320	-	6.9		"
168	I	An	WF9	2790	-	6.6		"
169	I	F+Fe	Ysl/Ysl	2910	920**	7.7	59	Fertilized
170	II	F+Fe	Ysl/Ysl	1620	40	8.5		"
171	III	F+Fe	Ysl/Ysl	2380	1180**	7.5		"
172	II	F+Fe	WF9	1640	810**	8.7	74	Fertilized
173	I	F+Fe	WF9	1750	560**	7.5		"
174	III	F+Fe	WF9	1410	0	7.9		"
175	II	F	WF9	830	-	5.5	66	Fertilized
176	I	F	WF9	1190	-	5.0		"
177	III	F	WF9	2090	-	4.9		"

Table 12. Continued.

Pot	Block	Soil treatment and variety		Yield	Yield increase[†]	Soil Fe	Plant Fe	Pre-treatment
				------mg--------		----ppm----		
178	III	F	Ysl/Ysl	1200	-	4.4	45	Fertilized
179	I	F	Ysl/Ysl	1990	-	4.6		"
180	II	F	Ysl/Ysl	1580	-	5.4		"

[†] $LSD_{.05}$ ΔY = 447.9 mg/pot